SECTION 506
STRUCTURAL STEEL

506.01. DESCRIPTION.

This work consists of furnishing, fabricating, and erecting steel structures and structural steel portions of other structures in accordance with these Specifications and the contract documents.

506.02. MATERIALS.

Conform to the requirements of the following Subsections.

Structural Steel	724.01
High-Strength Fasteners	724.02
Welding	724.03
Welded Stud Shear Connectors	724.04
Galvanizing	724.06
Cold Rolled Shafting for Pins and Rollers	725.02
Steel Castings	725.03
Iron Castings	725.04
Phosphor Bronze	725.06
Paint	730.02
Elastomeric Bearings Pads	733.06

506.04. CONSTRUCTION METHOD.

(a) **General.** For the fabrication of main-load carrying members such as trusses, arches, continuous beams, plate girders, bents, towers, and rigid frames, use a structural steel fabricating plant certified under the AISC Quality Certification Programs in the Major Steel Bridges Category. Use a fabricator who currently has an unrestricted certification under the AISC Quality Certification Programs in the Major Steel Bridges Category with endorsement "F," for the fabrication of "*fracture critical*" members. Fabricate "*fracture critical*" elements according to the AASHTO Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members.

Details of design which are permitted to be selected by the Contractor shall conform to the AASHTO *Standard Specification for Highway Bridges*.

Conform to the requirements of Section 512, "Painting," to paint structural steel. Paint all exposed surfaces of non-weathering grades of steel unless galvanized or otherwise specified; apply the inorganic zinc primer to the top flange of girders. Do not paint weathering steel unless otherwise specified in the contract documents. For superstructures made of weathering steel, blast-clean to the requirements of SSPC-SP6, "Commercial Blast Cleaning."

Before cutting or welding painted steel, remove all paint to bare metal within 3 inches (75mm) of the work. Comply with the requirements of Section 512. Repaint when finished.

Conform to the requirements of Section 502, "Temporary Structures," for falsework used to erect structural steel and for temporary bracing.

(b) **Notice of Beginning of Work.** Give written notice 21 calendar days before the beginning of work at the shop, so that inspection may be provided. Do not manufacture any material or perform any work in the shop before notification and before inspection is provided.

(c) **Inspection.** Structural steel will be inspected at the fabrication site according to Subsection 106.05.

Furnish a copy of all mill orders and certified mill test reports (Type A certificates). Show on the mill test reports the chemical analyses and physical test results for each heat of steel used in the work.

If approved, furnish Type D certificates from the fabricator, in lieu of mill test reports for material that normally is not supplied with mill test reports and for items such as fills, minor gusset plates, and similar material when quantities are small and the material is taken from stock.

Include in the certified mill test reports for steels with specified impact values, in addition to other test results, the results of Charpy V-notch impact tests. When fine-grain practice is specified, confirm on the test report that the material was so produced. Furnish copies of mill orders at the time orders are placed with the manufacturer. Furnish certified mill test reports and Type D certificates before the start of fabrication using material covered by these reports. Furnish, from the fabricator, a Type D Certificate for the fabrication.

Make material to be used available to the Engineer so that each piece can be examined. Provide the Engineer free access at all times to any portion of the fabrication site where material is stored or where work on the material is being performed.

The inspector will have the authority to reject materials or quality-of-work which does not fulfill the requirements of these Specifications. In cases of disputes, the Contractor may appeal to the Engineer, whose decision will be final.

Inspection at the mill or shop is intended as a means of facilitating the work and avoiding errors, and it is expressly understood that it shall not relieve the Contractor of any responsibility in regard to defective material or quality-of-work and the necessity for replacing the same at the Contractor's expense.

The inspector will stamp each piece accepted with a private mark. Any piece not so marked may be rejected. The acceptance of any material or finished members by the inspector shall not be a bar to subsequent rejection. Promptly replace or correct rejected materials and quality-of-work.

(d) **Working Drawings.** Prepare and submit drawings according to Subsection 105.02. Approval of the drawings covers the requirements for *"strength and detail"* only. The Department assumes no responsibility for errors in dimensions.

1. *Shop drawings.* Show full detailed dimensions and sizes of component parts of the structure and details of all miscellaneous parts (such as pins, nuts, bolts, drains, weld symbols, etc.) on shop drawings for steel structures.

   Adjust girder dimensions on the shop drawings to account for vertical curve, camber, dead load deflection, and grade since the girder detail on the plans is drawn and dimensioned as if the top flange of the girder were horizontal, with no accounting for these items.

Where specific orientation of plates is required, show the direction of rolling of plates. Cut flanges and webs of plate girders from plates so the long dimension of the girder parallels the rolling direction.

Identify on the shop drawings the type and grade of each piece that is to be made of steel.

Show on the shop drawings assembly marks that are cross-referenced to the original pieces of mill steel and their certified mill test reports.

The location of all shop welded splices shown on the shop drawings are subject to approval. Locate all shop welded splices to avoid points of maximum tensile or fatigue stress. Locate splices in webs at least 12 inches (300mm) from shop splices, butt joints in flanges, or stiffeners. Additional nondestructive tests may be required on shop welded splices.

Show on the shop drawings a complete set of bills of materials including pay weights.

2. *Erection drawings.* For all structural steel bridge members, provide erection drawings showing where the members are located in the structure. Identify members by erection mark.

   For steel superstructures that require engineered falsework support during erection under Section 502, submit drawings fully illustrating the proposed method of erection. Show details of all falsework bents and attachments to the bridge members. Show the sequence of erection and locations of lifting points. Calculations may be required to demonstrate that factored resistances are not exceeded and that member capacities and final geometry will be correct.

3. *Camber diagram.* Furnish a camber diagram with the shop drawings that shows the camber at each panel point of trusses or arch ribs and at the location of field splices and fractions of span length (tenth points minimum) of continuous beams and girders or rigid frames. When shown on the Plans, show camber at the locations shown on the Plans. On the camber diagram, show calculated cambers to be used in preassembly of the structure as required in Subsection 506.04(f)3.

4. *Transportation drawings.* If required, furnish transportation drawings for approval.

   Show all support points, tie-downs, temporary stiffening trusses or beams, and any other details needed to support and brace the member. Provide calculation sheets showing the dead load plus impact stresses induced by the loading and transportation procedure. Use impact stresses of at least 200% of the dead load stress. Use a total load, including impact, of not less than 300% of the dead load.

   Ship and store all members, both straight and curved, in their upright position.

(e) **Fabrication.**

1. *Identification of steels.* Use a system of assembly-marking individual pieces and cutting instructions to the shop (generally by cross referencing of the assembly-marks shown on the shop drawings with the corresponding item covered on the mill purchase order) that maintains the identity of the original piece.

   Material may be furnished from stock which can be identified by heat number and mill test report.

During fabrication, up to the point of assembling members, show clearly and legibly the specification of each piece of steel (other than Grade 36 (250) steel) by writing the material specification on the piece or using the identification color code shown in AASHTO M 160.

For other steels not included in AASHTO M 160, provide information on the color code used. Comply with the material identification requirements of AASHTO M 160.

Mark for grade by steel die stamping, or by a substantial, firmly attached tag, pieces of steel, other than Grade 36 (250) steel, that before assembling into members will be subject to fabricating operations, such as blast-cleaning, galvanizing, heating for forming, or painting, which might obliterate paint color code marking. Where the steel stamping method is used, place the impressions on the thicker tension-joint member in transition joints.

2. *Storage of Material.* Store structural material, either plain or fabricated, above the ground on platforms, skids, or other supports. Keep material free from dirt, grease, and other foreign matter and provide appropriate protection from corrosion. Store high-strength fasteners in accordance with Subsection 506.04(f)6.4.

3. *Plates.*

3.1 *Direction of rolling.* Unless otherwise shown in the contract documents, cut and fabricate steel plates for main members and splice plates for flanges and main tension members, not secondary members, so that the primary direction of rolling is parallel to the direction of the principal tensile and/or compressive stresses.

3.2 *Plate cut edges.*

3.2.1 *Edge planing.* Remove sheared edges on plates thicker than $^{5}/_{8}$ inch (16mm) to a depth of $^{1}/_{4}$ inch (6mm) beyond the original sheared edge, or beyond any re-entrant cut produced by shearing. Fillet re-entrant cuts before cutting to a minimum radius of $^{3}/_{4}$ inch (20mm).

3.2.2 *Oxygen Cutting*. Oxygen cut structural steel according to ANSI/AASHTO/AWS Bridge Welding Code D1.5.

3.2.3 *Visual Inspection and Repair of Plate Cut Edges*. Visually inspect and repair plate cut edges. The cut edges shall conform to ANSI/AASHTO/AWS Bridge Welding Code D1.5.

3.3 *Bent plates.*

3.3.1 *General.* Furnish unwelded, load-carrying, rolled-steel plates to be bent as specified herein.

Take material from the stock plates such that the bend line will be at right angles to the direction of rolling, except that cold-bent ribs for orthotopic-deck bridges may be bent with bend lines in the direction of rolling.

Before bending, round the corners of the plates to a radius of $^{1}/_{16}$ inch (2mm) throughout the portion of the plate where the bending occurs.

3.3.2 *Cold bending*. Cold bend so that no cracking of the plate occurs. Use the minimum bend radii shown in Table 506-1 measured to the concave face of the metal.

Table 506-1

Minimum Bending Radii

Plate Thickness - t, inches (mm)	Bending Radius*
Less than 1/2 (12)	2(t)
Over ½ to 1 (12 to 25)	2.5(t)
Over 1 to $1^1/_2$ (25 to 38)	3(t)
Over $1^1/_2$ to $2^1/_2$ (38 to 60)	3.5(t)
Over $2^1/_2$ to 4 (60 to 100)	4(t)

*Bend radii for all grades of structural steel.

Allow for springback of Grades 100 (690) and 100W (690W) steels equal to about three times that for Grade 36 (250) steel. Use a lower die span of at least 16 times the plate thickness for break press forming. Make multiple hits.

3.3.3 *Hot bending*. If a radius shorter than the minimum specified for cold bending is essential, hot bend the plates at a temperature not greater than 1200°F (650°C), except for Grades 70W (485W, 100 (690), and 100W (690W). If Grades 100 (690) and 100W (690W) steel plates are heated to a temperature greater than 1100°F (595°C) or, Grade 70W (grade 485W) steel plates are heated to a temperature greater than 1050°F (565°C), requench and temper according to the producing mill's standard practice and, when directed, tested to verify restoration of specified properties.

4. *Stiffeners.* Provide bearing stiffeners in pairs, one on each side of the web. Mill to bear at the bottom flange and tight fit at the top flange. Provide fillet welds ($^5/_{16}$ inch (8mm), unless otherwise specified) on both sides of the bearing stiffener, at the web and top and bottom flanges. Allow the fit of the bearing stiffener to the flanges to be inspected before covering with weld. Install bearing stiffeners to be vertical in the finished structure.

Fabricate intermediate stiffeners not intended to support concentrated loads to provide a tight fit against both flanges. Provide fillet welds ($^1/_4$ inch (6mm), unless other wise specified) on both sides of the stiffener at the web and compression flange. On exterior girders, place all intermediate stiffeners on the outside of the web. On interior girders, alternate sides of the web when placing intermediate stiffeners.

Provide diaphragm stiffeners in pairs, one on each side of the web. Fabricate diaphragm stiffeners to provide a tight fit against both flanges. Provide fillet welds ($^1/_4$ inch (6mm), unless otherwise specified) on both sides of the stiffener, at the web and top and bottom flanges.

Clip the corners of stiffeners at flange-web intersections. If clip dimensions are not shown on the plans, use the following clip dimensions:

- along the flange:$1^1/_2$ inches (38mm),
- along the web: 4 to 6 times the web thickness, but not less than $1^1/_2$ inches (38mm), nor more than 3 inches (75mm).

5. *Abutting joints.* Mill or saw-cut abutting joints in compression members of trusses and columns to give a square joint and uniform bearing. The maximum allowed opening at other joints, not required to be faced, is $^{3}/_{8}$ inch (10mm).

6. *Facing of bearing surfaces.* Finish bearing and base plates and other bearing surfaces that will come in contact with each other or with concrete to the ANSI surface roughness defined in ANSI B46.1, *Surface Roughness, Waviness and Lay, Part I*, as shown in Table 506-2.

Table 506-2
ANSI Surface Roughness Values

Bearing Surface	Surface Roughness Value µ-inch (µm)
Steel slabs	2000 (50)
Heavy plates in contact in shoes to be welded	1000 (25)
Milled ends of compression members, milled or ground ends of stiffeners and fillers	500 (13)
Bridge rollers and rockers	250 (6)
Pins and pin holes	125 (3)
Sliding bearings	125 (3)

Machine sliding bearings that have a surface roughness greater than ANSI 60 (2µm) so the lay of the cut is parallel to the direction of movement.

Fabricate parts in bearing to provide a uniform even contact with the adjacent bearing surface when assembled. Limit the maximum gap between bearing surfaces to 0.040 inch (1mm). Base and sole plates that are plane and true and have a surface roughness not exceeding the above tabulated values need not be machined, except machine sliding surfaces of base plates.

Do not machine surfaces of fabricated members until all fabrication on that particular assembly or subassembly is complete. Machine metal components that are to be heat treated after heat treatment.

7. *Straightening material.* If approved, straighten plates, angles, other shapes, and built-up members by methods that will not produce fracture or other damage to the metal. Straighten distorted members by mechanical means or, if approved, by carefully planned procedures and supervised application of a limited amount of localized heat. Use rigidly controlled procedures and do not exceed the temperatures specified in Table 506-3 when heat straightening Grades 70W, 100 and 100W (grades 485W, 690, and 690W) steel members.

Table 506-3
Heat Straightening Temperatures

Material to be Straightened	Maximum Temperature
Grade 70W(485W) > 6 inches(150mm) from weld	1050°F (565°C)
Grade 70W(485W) < 6 inches (150mm)from weld	900°F (480°C)
Grade 100(690) or 100W(690W) > 6 inches (150mm)from weld	1100°F (595°C)
Grade 100(690) or 100W(690W) < 6 inches (150mm)from weld	950°F (510°C)

In all other steels, do not exceed 1200°F (650°C) in the heated area. Control the application by temperature-indicating crayons, liquids, or bimetal thermometers. Heating in excess of the limits shown shall be cause for rejection, unless the Engineer allows testing to verify material integrity.

Keep parts to be heat straightened substantially free of external forces and stress, except stresses resulting from mechanical means used in conjunction with the application of heat.

Evidence of fracture following straightening of a bend or buckle will be cause for rejection of the damaged piece.

8. *Bolt Holes*.

8.1 *Holes for High-Strength Bolts and Unfinished Bolts.*

8.1.1 *General*. Make bolt holes to the dimensions given in Table 506-4 for standard, oversize, short slotted, and long slotted holes. Provide oversize, short slotted, and long slotted holes only when specified in the contract documents.

Table 506-4 (English)
Bolt Hole Sizes (inches)

Bolt Diameter (d)	Standard (Diameter)	Oversize (Diameter)	Short Slot (Width x Length)	Long Slot (Width x Length)
$^5/_8$	$^{11}/_{16}$	$^{13}/_{16}$	$^{11}/_{16}$ x $^7/_8$	$^{11}/_{16}$ x $1^9/_{16}$
$^3/_4$	$^{13}/_{16}$	$^{15}/_{16}$	$^{13}/_{16}$ x 1	$^{13}/_{16}$ x $1^7/_8$
$^7/_8$	$^{15}/_{16}$	$1^1/_{16}$	$^{15}/_{16}$ x $1^1/_8$	$^{15}/_{16}$ x $2^3/_{16}$
1	$1^1/_{16}$	$1^1/_4$	$1^1/_{16}$ x $1^5/_{16}$	$1^1/_{16}$ x $2^1/_2$
$1^1/_8$	d+$^1/_{16}$	d+$^5/_{16}$	d+$^1/_{16}$ x d+$^3/_8$	d+$^1/_{16}$ x 2.5d

Table 506-4 (Metric)
Bolt Hole Sizes (mm)

Bolt Dia. (d) (d)	Standard (Dia.)	Oversize (Dia.)	Short Slot (Wid. X Len.)	Long Slot (Wid. X Len.)
16	18.0	20.0	18.0 x 22.0	18.0 x 40.0
20	22.0	24.0	22.0 x 26.0	22.0 x 50.0
22	24.0	28.0	24.0 x 30.0	24.0 x 55.0
24	27.0	30.0	27.0 x 32.0	27.0 x 60.0
27	30.0	35.0	30.0 x 37.0	30.0 x 67.0
30	33.0	38.0	33.0 x 40.0	33.0 x 75.0

Punch or drill all bolt holes, except as noted herein. Material forming the parts of a member composed of not more than 5 thicknesses of metal may be punched full-size whenever the thickness of the material is not greater than $^3/_4$ inch (20mm) for structural steel, $^5/_8$ inch (16mm) for high-strength steel, or $^1/_2$

inch (12mm) for quenched and tempered alloy steel, unless subpunching and reaming is required under Subsection 506.04(e)8.5, the preparation of field connections.

When material is thicker than $^{3}/_{4}$ inch (20mm) for structural steel, $^{5}/_{8}$ inch (16mm) for high-strength steel, or $^{1}/_{2}$ inch (12mm) for quenched and tempered alloy steel, either subdrill and ream or drill full-size all holes. If required, either subpunch or subdrill (subdrill if thickness limitation governs) $^{1}/_{4}$ inch (6mm) smaller and, after assembling, ream $^{1}/_{16}$ inch (2mm) larger or drill full size.

8.1.2 *Punched holes.* Use a die diameter that is not more than $^{1}/_{16}$ inch (2mm) larger than the punch diameter. Ream holes that require enlarging to admit bolts. Clean cut the holes without torn or ragged edges. The slightly conical hole that naturally results from punching operations shall be considered acceptable.

8.1.3 *Reamed or drilled holes.* Ream or drill holes so they are cylindrical and perpendicular to the member. Where practical, direct reamers by mechanical means. Remove burrs on the outside surfaces. Ream and drill with twist drills, twist reamers, or roto-broach cutters. Assemble and securely hold together connecting parts that are being reamed or drilled and match-mark before disassembling.

8.1.4 *Accuracy of holes.* Holes not more than $^{1}/_{32}$ inch (1mm) larger in diameter than the true decimal equivalent of the nominal diameter of the drill or reamer are acceptable. The slightly conical hole resulting from punching operations is acceptable. The width of slotted holes produced by flame cutting or a combination of drilling or punching and flame cutting shall be no more than $^{1}/_{32}$ inch (1mm) greater than the nominal width. Grind flame cut surfaces smooth.

8.2 *Accuracy of Hole Group.*

8.2.1 Accuracy before reaming. Accurately punch full size, subpunched, or subdrilled holes so that after assembling (before any reaming is done) a cylindrical pin $^{1}/_{8}$ inch (3mm) smaller in diameter than the nominal size of the punched hole may be entered perpendicular to the face of the member, without drifting, in at least 75% of the contiguous holes in the same plane. Punched pieces not meeting this requirement will be rejected. Holes, through which a pin $^{3}/_{16}$ inch (5mm) smaller in diameter than the nominal size of the punched hole cannot be inserted, will be rejected.

8.2.2 *Accuracy after reaming.* After reaming, the maximum allowed offset of 85% of any contiguous group of holes through adjacent thicknesses of metal is $^{1}/_{32}$ inch (3mm).

Use steel templates having hardened steel bushings in holes accurately dimensioned from the centerlines of the connection as inscribed on the template. Use connection centerlines when locating templates from the milled or scribed ends of members.

8.3 *Numerically-controlled drilled field connections.* In lieu of drilling undersized holes and reaming while assembled, or drilling holes full-size while assembled, drilling or punching bolt holes full-size in unassembled pieces and/or connections, including templates for use with matching undersized and reamed holes by means of suitable numerically-controlled (N/C) drilling or punching equipment is allowed.

8.4 *Holes for ribbed bolts, turned bolts, or other approved bearing-type bolts.* Subpunch or subdrill holes for ribbed bolts, turned bolts, or other approved bearing-type bolts, $^{3}/_{16}$ inch (5mm) smaller than the nominal diameter of the bolt and ream when assembled, or drill from the solid. Provide finished holes with a driving fit.

8.5 *Preparation of field connections.* Subpunch or subdrill and ream while assembled, or drill full size to a steel template, holes in all field connections and field splices of main members of trusses, arches, continuous beam spans, bents, towers (each face), plate girders, and rigid frames.

Holes for field splices of rolled beam stringers continuous over floor beams or cross frames may be drilled full-size unassembled to a steel template. Holes for floor beams or cross frames may be drilled full size unassembled to a steel template. Subpunch and ream while assembled, or drill full size to a steel template, all holes for floor beam and stringer field end connections.

When reaming or drilling full size field connection holes through a steel template, carefully locate and position the template and firmly bolt in place, before drilling. Use exact duplicates of templates used for reaming matching members, or the opposite faces of a single member. Accurately locate templates used for connections on like parts or members so that the parts or members are duplicates and require no match-marking.

For any connection, in lieu of subpunching and reaming or subdrilling and reaming, holes drilled full-size through all thicknesses or material assembled in proper position may be used.

9. *Pins and Rollers.*

9.1 *General.* Accurately fabricate pins and rollers that are straight, smooth, and free from flaws. Forge and anneal pins and rollers more than 9 inches (230mm) in diameter. Pins and rollers 9 inches (230mm) or less in diameter may be either forged and annealed or cold-finished carbon-steel shafting.

In pins larger than 9 inches (230mm) in diameter, bore a hole not less than 2 inches (50mm) in diameter full length along the pin axis after the forging has been allowed to cool to a temperature below the critical range (under suitable conditions to prevent damage by too rapid cooling and before being annealed).

9.2 *Boring pin holes.* Bore pin holes true to the specified diameter, smooth and straight, at right angles with the axis of the member and parallel with each other. Produce the final surface using a finishing cut.

Produce a pin hole diameter that does not exceed that of the pin by more than 0.020 inches (0.5mm) for pins 5 inches(125mm) or less in diameter, or by $^{1}/_{32}$ inch (1mm) for larger pins.

The maximum allowed variation of the outside-to-outside distance of end holes in tension members and the inside-to-inside distance of end holes in compression members is $^{1}/_{32}$ inch (1mm) from that specified. Bore pin holes in built-up members after the member has been assembled.

9.3 *Threads for bolts and pins.* Provide threads on all bolts and pins for structural steel construction that conform to screw threads Profile ANSI B1.13 (B1.13M) with a tolerance Class 6G for external threads and Class 6H for internal threads.

10. *Eyebars.* Pin holes may be flame cut at least 2 inches (50mm) smaller in diameter than the finished pin diameter. Securely fasten together (in the order to be placed on the pin) all eyebars that are to be placed side by side in the structure and bore at both ends while clamped. Pack and match-mark eyebars for shipment and erection. Stamp with steel stencils, so as to be visible when the bars are nested in place on the structure, all identifying marks on the edge of one head of each member after fabrication is completed. Use low-stress type steel die stamps. Do not weld on eyebars.

Provide eyebars, straight and free from twists, with pin holes accurately located on the centerline of the bar. Do not allow the inclination of any bar to the plane of the truss to exceed a slope of 0.5 percent.

Simultaneously cut the edges of eyebars that lie between the transverse centerline of their pin holes with two mechanically operated torches abreast of each other, guided by a substantial template to prevent distortion of the plates.

11. *Annealing and Stress Relieving.* When structural members are indicated in the contract documents to be annealed or normalized, machine, finish bore, and straighten annealed or normalized these members subsequent to heat treatment. Normalize and anneal (full annealing) according to ASTM A919. Maintain uniform temperatures throughout the furnace during the heating and cooling so that the temperature at no two points on the member will differ by more than 100°F at any time.

Do not anneal or normalize members of Grades 100/100W (690/690W) or Grade 70W(485W) steels. Stress relieve these grades only with approval.

Record each furnace charge, identify the pieces in the charge and show the temperatures and schedule actually used. Provide proper instruments, including recording pyrometers, for determining at any time the temperatures of members in the furnace. Make records of the treatment operation available for approval. The maximum allowed holding temperature for stress relieving Grades 100/100W (690/690W) and Grade 70W (485W) steels is 1100°F (595°C) and 1050°F (565°C), respectively.

Stress relieve members, such as bridge shoes, pedestals, or other parts that are built up by welding sections of plate together, according to Subsection 4.4 of ANSI/AASHTO/AWS Bridge Welding Code D1.5.

12. *Curved Girders.*

12.1 *General.* Flanges of curved, welded girders may be cut to the radii specified in the contract documents or curved by applying heat as required by these Specifications providing the radii is not less than allowed the AASHTO Standard Specifications for Highway Bridges.

12.2 *Heat Curved Rolled Beams and Girders.*

12.2.1 *Materials.* Do not heat curve steels that are manufactured to a specified minimum yield point greater than 50 ksi (345MPa).

12.2.2 *Type of Heating.* Beams and girders may be curved either continuous or V-type heatings as approved by the Engineer.

For the continuous method, heat a strip along the edge of the top and bottom flange simultaneously. Make the strip of sufficient width and temperature to obtain the required curvature.

For the V-type heating, heat the top and bottom flanges in truncated triangular or wedge-shaped areas having their base along the flange edge and spaced at regular intervals along each flange. Use the spacing and temperature as required to obtain the required curvature, heating along the top and bottom flange at approximately the same rate. Terminate the apex of the truncated triangular area applied to the inside flange surface just before the juncture of the web and the flange is reached. To avoid unnecessary web distortion, take special care when heating the inside flange surfaces (the surfaces that intersect the web) so that heat is not applied directly to the web. When the radius of curvature is 1000 feet (300m) or more, extend the apex of the truncated triangular heating pattern applied to the outside flange surface to the juncture of the flange and web. When the radius of curvature is less than 1000 feet (300m), extend the apex of the truncated triangular heating pattern applied to the outside flange surface past the web for a distance equal to $^1/_8$ of the flange width or 3 inches (75mm), whichever is less. The truncated triangular pattern shall have an included angle of approximately 15 to 30 degrees but the base of the triangle shall not exceed 10 inches (250mm). Variations in the patterns prescribed above may be made with the approval of the Engineer.

For both types of heating, the flange edges to be heated are those that will be on the inside of the horizontal curve after cooling. Heating both inside and outside flange surfaces is only mandatory when the flange thickness is $1^1/_4$ inch (32mm) or greater, in which case, heat the two surfaces concurrently. The maximum temperature shall be as prescribed below.

12.2.3 *Temperature.* Conduct the heating-curving operation in such a manner that the temperature of the steel does not exceed 1150°F (620°C) as measured by temperature-indicating crayons or other suitable means. Do not artificially cool the girder until after naturally cooling to 600°F (315°C). The method of artificial cooling shall be subject to the approval of the Engineer.

12.2.4 *Position for Heating.* The girder may be heat-curved with the web in either a vertical or horizontal position. When curved in the vertical position, brace or support the girder in such a manner that the tendency of the girder to deflect laterally during the heat-curving process will not cause the girder to overturn.

When curved in the horizontal position, support the girder near its ends and at the intermediate points, if required, to obtain a uniform curvature; the

bending stress in the flanges due to the dead load of the girder must not exceed the usual allowable design stress. When the girder is positioned horizontally for heating, maintain intermediate safety catch blocks at the midlength of the girder within 2 inches (50mm) of the flanges at all times during the heating process to guard against a sudden sag due to plastic flange buckling.

12.2.5 *Sequence of Operations.* Heat-curve the girder in the fabrication shop before it is painted. The heat-curving operation may be conducted either before or after all the required welding of transverse intermediate stiffeners are completed. However, unless provisions are made for girder shrinkage, locate and attach connection plates and bearing stiffeners after heat curving. If longitudinal stiffeners are required, heat-curve or oxygen-cut the stiffeners separately and then weld to the curved girder. When cover plates are to be attached to rolled beams, they may be attached before curving if the total thickness of one flange and cover plate is less than $2^{1}/_{2}$ inches (65mm) and the radius of curvature is greater than 1000 feet (300m). For other rolled beams with cover plates, heat-curve the beams before the cover plates are attached; either heat-curve or oxygen-cut cover plates separately and then weld to the curved beam.

12.2.6 *Camber.* Perform cambering of girders before heat curving. Camber for rolled beams may be obtained by heat-cambering methods approved by the Engineer. For plate girders, cut the web to the prescribed camber with suitable allowance for shrinkage due to cutting, welding, and heat curving. The heat-curving process may tend to change the vertical camber present before heating. This effect will be most pronounced when the top and bottom flanges are of unequal widths on a given transverse cross section. However, subject to the approval of the Engineer, moderate deviations from specified camber may be corrected by a carefully supervised application of heat.

12.2.7 *Measurement of Curvature of Camber.* Horizontal curvature and vertical camber shall be measured for final acceptance after all welding and heating operations are completed and the flanges have cooled to a uniform temperature. Check horizontal curvature with the girder in the vertical position.

13. *Full-Size Tests.* When full-size tests of fabricated structural members or eyebars are required in the contract documents, provide suitable facilities, material, supervision, and labor necessary for making and recording the required tests.

14. *Marking and Shipping.* Paint and mark each member with an erection mark for identification. Use the corresponding marks from the approved working drawings.

Furnish as many copies of material orders, shipping statements, and erection drawings, as the Engineer directs. Show the weight of the individual members on the statements. Mark thereon the weight of members over 6000 pounds (3000kg).

Load structural members on trucks or cars in such a manner that they may be transported and unloaded at their destination without being excessively stressed, deformed, or otherwise damaged.

Ship bolts, nuts, washers, and other fastener components from each rotational-capacity lot in the same container. If there is only one production lot number for each size of nut and washer, the nuts and washers may be shipped in separate containers. Ship pins, small parts, and packages of bolts, nuts, and washers in boxes, crates, kegs, or barrels, not exceeding 300 pounds (140kg) gross weight per package. Plainly mark a list and description of the contained materials on the outside of each shipping container.

(f) **Assembly.**

1. *Bolting.* Clean surfaces of metal in contact before assembling. Assemble parts of a member. Securely pin and firmly draw together before drilling, reaming, or bolting is commenced. Take assembled pieces apart for the removal of burrs and shavings produced by the operation. Assemble members to be free from twists, bends, and other deformation.

   Drift during assembling only enough to bring the parts into position without enlarging holes or distorting the metal.

   Place a washer under the element of the bolted assembly that is turned during installation.

2. *Welded Connections.* Fabricate surfaces and edges to be welded smooth, uniform, clean, and free of defects that would adversely affect the quality of the weld. Prepare edges according to ANSI/AASHTO/AWS *Bridge Welding Code D1.5*.

3. *Preassembly of Field Connections.*

   3.1 *General.* Preassemble field connections of main members of trusses, arches, continuous beams, plate girders, bents, towers, and rigid frames before erection to verify the geometry of the completed structure or unit and to verify or prepare field splices. Submit the method and details of preassembly for approval. Use methods and details of preassembly that are consistent with the procedure shown on the approved erection drawings and camber diagrams.

   Preassemble at least 3 contiguous panels or sections that are accurately adjusted for line and camber. For successive assemblies include at least one panel or section of the previous assembly (repositioned if necessary and adequately pinned to assure accurate alignment) plus 2 or more sections or panels added at the advancing end. For structures longer than 150 feet (50m), make each assembly not less than 150 feet (50m) long regardless of the length of individual continuous panels or sections. Assembly may start from any location in the structure and proceed in one or both directions as long as preceding requirements are satisfied.

   3.2 *Bolted connections.* Prepare bolted connections holes as specified in Subsection 506.04(e)8. Where applicable, assemble major components with milled ends of compression members in full bearing and then ream subsized holes to the specified size while the connections are assembled.

   3.3 *Check assembly/numerically-controlled drilling.* When using numerically controlled drilling or punching, make a check assembly for each major structural type of each project. Fabricate the check assembly of at least 3 contiguous shop sections or, for a truss, all members in at least 3 contiguous panels but not less than the number of panels associated with 3 contiguous chord lengths (such as the length between field splices). Base check assemblies on the proposed order of erection, joints in bearings, special

complex points, and similar considerations. Shop assemblies other than the check assemblies are not required.

If the check assembly fails in some specific manner to demonstrate that the required accuracy is being obtained, further check assemblies may be required for which there shall be no additional cost to the Department.

Receive approval of each assembly (including camber, alignment, accuracy of holes, and fit of milled joints) before reaming is commenced or before any N/C drilled check assembly is dismantled.

3.4 *Field welded connections.* Field welded connections are prohibited unless specifically specified in the contract documents. Verify the fit of members (including the proper space between abutting flanges) with the segment preassembled in accordance with Subsection 506.04(f)3.1.

4. *Match Marking.* Match mark connecting parts preassembled in the shop to assure proper fit in the field. Provide a diagram showing such match-marks.

5. *Connections Using Unfinished, Turned, or Ribbed Bolts.*

5.1 *General.* Use unfinished, turned, or ribbed bolts, where specified, conforming to the requirements for carbon and alloy steel externally threaded fasteners, ASTM A 568, Property Class 4.6, 60 ksi (400MPa) tensile strength. Use bolts with single self-locking nuts or double nuts. Use beveled washers where bearing faces have a slope of more than 1:20 with respect to a plane normal to the bolt axis. Note that the specifications of this Subsection 506.04(f)5.1 do not pertain to the use of high-strength bolted connections, which are covered in Subsection 506.04(f)6.

5.2 *Turned bolts.* Furnish turned bolts with a body surface ANSI roughness not exceeding 125 (3.2mm). Furnish hex headed bolts and nuts of the nominal size specified. Carefully ream holes for turned bolts and furnish bolts to provide for a light driving fit. Keep bolt threads entirely outside of the holes. Provide a washer under the nut.

5.3 *Ribbed bolts.* Use approved form of ribbed body with continuous longitudinal ribs. Provide a body diameter measured on a circle through the points of the ribs $^{1}/_{16}$ inch (2mm) greater than the nominal diameter specified for the bolts.

Furnish ribbed bolts with round heads conforming to ANSI B18.5.2.2M or B18.5.2.3M as specified. Furnish hexagonal nuts that are either recessed or have a washer of suitable thickness. Ribbed bolts shall have a driving fit when installed in holes. Provide sufficiently hard ribs such that the ribs do not compress or deform and allow the bolts to turn in the holes during tightening. If the bolt twists before drawing tight, ream the hole and provide an oversized replacement bolt.

6. *Connections Using High-Strength Bolts.*

6.1 *General.* This subsection covers the assembly of structural joints using AASHTO M 164 or AASHTO M 253 high-strength bolts, or equivalent fasteners, tightened to a high tension. Install bolts in holes conforming to Subsection 506.04(e)8. Use direct tension indicators (DTIs) on all connections using high-strength bolts, unless otherwise specified in the contract documents.

6.2 *Bolted parts.* Use steel material within the grip of the bolt with no compressible material such as gaskets or insulation. Fabricate bolted steel parts to fit solidly together after the bolts are tightened. Limit the maximum slope of the surfaces of parts in contact with the bolt head or nut to 1:20 with respect to a plane normal to the bolt axis.

6.3 *Surface conditions.* In painted joints including slip-critical joints, paint the faying surfaces with inorganic zinc primer of the Inorganic Zinc/Epoxy/Urethane (IZ-E-U) paint system specified in Subsection 730.02. Before blast-cleaning and painting, remove burrs that would prevent solid seating of the connected parts in the snug-tight condition. At the time of assembly, clean all joint surfaces (including surfaces adjacent to the bolt head and nut) of dirt or foreign material. Repair damage that would prevent solid seating of the connected parts in the snug-tight condition

If a paint system other than the IZ-E-U system is specified, paint the faying surfaces only if the primer is a Class B classification, minimum slip coefficient of 0.50, as tested by the "Test Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints" from the Research Council on Structural Connections. Otherwise, treat the joint as a non-painted joint. Do not assemble painted joints before the primer has cured for the minimum time used in the qualifying test.

In non-painted joints, exclude paint (including any inadvertent overspray) from areas closer than one bolt diameter, but not less than 1 inch (25mm), from the edge of any hole and all areas within the bolt pattern. At the time of assembly, clean all joint surfaces (including surfaces adjacent to the bolt head and nut) of dirt or foreign material and scale, except tight mill scale. Remove burrs that would prevent solid seating of the connected parts in the snug-tight condition.

For faying surfaces to be galvanized, hot-dip galvanize in accordance with AASHTO M 111 and hand roughen by means of hand wire brushing. Do not use a power wire brush.

6.4 *Installation.*

6.4.1 *General.* Install fasteners of the same lot number together. Protect fasteners from dirt and moisture. Take from protected storage only as many fasteners as are anticipated to be installed and tightened during a work shift. Return to protected storage fasteners not used at the end of the shift. Do not clean lubricant from fasteners that is required to be present in the as-delivered condition. Clean, re-lubricate, and test for rotational capacity before installation, fasteners for slip-critical connections which accumulate rust or dirt. Lubricate all galvanized nuts with a lubricant containing a visible dye. Provide plain bolts that are "oily" to the touch when delivered and installed. Remove lubricant before painting.

Provide a tension measuring device (a Skidmore-Wilhelm calibrator or other acceptable bolt tension indicating device) at all job sites where high-strength fasteners are being installed and tightened. Use the tension measuring device to perform the rotational-capacity test and to confirm:

- the requirements of Table 506-5 of the complete fastener assembly,
- the calibration of the wrenches, if applicable, and
- the understanding and proper use by the bolting crew of the tightening method.

For short grip bolts, direct tension indicators (DTI) with solid plates may be used to perform this test. First check the DTI with a longer grip bolt in the Skidmore-Wilhelm calibrator. The frequency of confirmation testing, number of tests to be performed, and test procedure shall conform to the requirements for turn-of-nut tightening and direct tension indicator tightening methods as applicable (see Subsection 506.04(f)6.4.4, *Turn-of-nut tightening* and Subsection 506.04(f)6.4.6, *Direct tension indicator tightening*). Confirm the accuracy of the tension measuring device by an approved testing agency at least annually.

Install fasteners together with washers of size and quality specified, located as required below, in properly aligned holes and tightened by the methods described in this specification inclusive to at least the minimum tension specified in Table 506-5 after all the fasteners are tight. Where the use of direct tension indicators is specified, use the direct tension indicator method of tightening.

TABLE 506-5
Minimum Required Bolt Tension [1]

Bolt Size-inches	AASHTO M 164 ASTM A 325 (pounds)	AASHTO M 253 ASTM A 490 (pounds)
5/8	19,000	24,000
3/4	28,000	35,000
7/8	39,000	49,000
1	51,000	64,000
1 1/8	56,000	80,000
1 1/4	71,000	102,000

[1] Equal to 70% of the specified minimum tensile strength of bolts (as specified in ASTM Specifications for tests of full size ASTM A 325 and ASTM A 490 bolts with coarse thread series, ANSI B1.13, loaded in axial tension) rounded to the nearest 1000 pounds.

TABLE 506-5 (Metric)
Minimum Required Bolt Tension [2]

Bolt Size-mm	AASHTO M 164 ASTM A 325M (kN)	AASHTO M 253 ASTM A 490M (kN)
16	91.2	114
20	142	179
22	176	221
24	205	257
27	267	334
30	326	408
36	476	595

[2] Equal to 70% of the specified minimum tesile strength of bolts (as specified in ASTM Specifications for tests of full size ASTM A 325M and ASTM A 490M bolts with metric coarse thread series, ANSI B1.13M, loaded in axial tension) rounded to the nearest 0.1 kN.

If approved, tightening may be performed by turning the bolt while the nut is prevented from rotating when it is impractical to turn the nut. If impact wrenches are used, provide adequate capacity and sufficient air to tighten each bolt in approximately 10 seconds.

Do not reuse AASHTO M 253 fasteners and AASHTO M 164 fasteners. Touching up or re-tightening previously tightened bolts that may have been loosened by the tightening of adjacent bolts will not be considered as re-use, provided the snugging up continues from the initial position and does not require greater rotation, including the tolerance, than that required by Table 506-6.

TABLE 506-6 [a]
Nut Rotation from the Snug-Tight Condition[b][d]
Geometry of Outer Faces of Bolted Parts

Bolt length measured from underside of head to end of bolt	Both faces normal to bolt axis	One face normal to bolt axis and other face sloped not more than 1:20. (Bevel washers not used)	Both faces normal to bolt axis and other face sloped not more than 1:20. (Bevel washers not used)
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8 diameters	1/2 turn	2/3 turn	5/6 turn
Over 8 diameters but not exceeding 12 diameters[c]	2/3 turn	5/6 turn	1 turn

(a) Applicable only to connections where all material within the grip of the bolt is steel.

(b) Nut rotation is relative to bolt, regardless of the element (nut or bolt) being turned. The tolerance is ±30° for bolts installed by ½ turn or less. The tolerance is ±45° for bolts installed by 2/3 turn or more.

(c) For bolt lengths greater than 12 diameters, determine the required rotation by actual tests in a suitable tension device simulating the actual conditions.

(d) *Snug-tight* is defined as the tightness that exists when the plies of the joint are in firm contact. This may be attained by a few impacts of an impact wrench or the full effort of a worker using an ordinary spud wrench.

Install bolts in all holes of the connection and bring to a snug-tight condition. Systematically progress with snug-tightening from the most rigid part of the connection to the free edges. Retighten the bolts of the connection in a similar systematic manner as necessary until all bolts are simultaneously snug-tight and the connection is fully compacted.

6.4.2 *Rotational-capacity tests.* Subject high-strength fasteners, black and galvanized, to job-site rotational-capacity tests performed according to AASHTO M 164 and the following.

a. Include washers as part of the test even if they may not be required as part of the installation procedure.

b. Test each combination of bolt production lot, nut lot, and washer lot as an assembly. Where washers are not required by an installation procedures, they need not be included in the lot identification.

c. Assign a rotational-capacity lot number to each combination of lots tested.

d. Test at a minimum frequency of 2 assemblies per rotational-capacity lot.

e. For bolts that are long enough to test in a Skidmore-Wilhelm Calibrator, assemble and test the bolt, nut, and washer assembly in a Skidmore-Wilhelm Calibrator or approved equivalent device.

f. For bolts that are too short to test in a Skidmore-Wilhelm Calibrator, test the assembly in a steel joint. The tension requirement in Subsection 506.04(f)6.4.2*h*, need not apply. Compute the maximum torque requirement,

$$\text{Torque} \leq 0.25\ PD,$$

using a value of P equal to the turn test tension (1.15 times the fastener tension in Table 506-5).

g. After tightening to a snug-tight condition, tighten the fastener 2 times the required number of turns indicated in Table 506-5, in a Skidmore-Wilhelm Calibrator or equivalent tension measuring device, without stripping or failure.

h. During this test, the maximum recorded tension must be equal to or greater than the turn test tension which is 1.15 times the required fastener tension indicated in Table 506-5.

i. After exceeding the turn test tension required above, take and record one reading of tension and torque. The measured torque at a tension "P" shall conform to the following equation:

$$\text{Torque} \leq 0.25\ PD$$

where: Torque = Measured torque (foot·pounds) [Newton ° meter]
P = Measured bolt tension (pounds) [kilo Newtons]
D = Bolt diameter (feet) [millimeters]

6.4.3 Washers. Where the outer face of the bolted parts has a slope greater than 1:20 with respect to a plane normal to the bolt axis, use a hardened beveled washer to compensate for the lack of parallelism.

Use hardened square or rectangular beveled washers for American Standard Beams and Channels conforming to AASHTO M 293.

Where necessary, washers may be clipped on one side not closer than 7/8 of the bolt diameter from the center of the washer.

Hardened washers not required for connections using AASHTO M 164 and AASHTO M 253 bolts except under the following conditions.

- Use hardened washers under both the head and the nut when AASHTO M 253 bolts are installed in material having a specified yield point less than 40 ksi (275MPa) regardless of the tightening method.
- Use a hardened washer conforming to AASHTO M 293 where AASHTO M 164 bolts of any diameter or AASHTO M 253 bolts equal to or less than

1 inch (24mm) in diameter are to be installed in oversize or short-slotted holes in an outer ply.

- Use hardened washers conforming to AASHTO M 293, except with $^{5}/_{16}$ inch (8mm) minimum thickness, under both the head and the nut in lieu of standard thickness hardened washers where AASHTO M 253 bolts more than 1 inch (24mm) in diameter are to be installed in an oversize or short-slotted hole in an outer ply. Multiple hardened washers with combined thickness equal to or greater than $^{5}/_{16}$ inch (8mm) do not satisfy this requirement.
- Where AASHTO M 164 bolts of any diameter or AASHTO M 253 bolts equal to or less than 1 inch (24mm) in diameter are installed in a long-slotted hole in an outer ply, provide a plate washer or continuous bar of at least $^{5}/_{16}$ inch (8mm) thickness with standard holes with sufficient size to cover the slot after installation and is structural grade material that need not be hardened. When AASHTO M 253 bolts over 1 inch (24mm) in diameter are used in long-slotted holes in external plies, use a single hardened washer conforming to AASHTO M 293 with a $^{5}/_{16}$ inch (8mm) minimum thickness in lieu of washers or bars of structural grade material. Multiple hardened washers with combined thickness equal to or greater than $^{5}/_{16}$ inch (8mm) do not satisfy this requirement.

  Alternative design fasteners, meeting the requirements of Subsection 724.02 with geometry which provides a bearing circle on the head or nut with a diameter equal to or greater than the diameter of hardened washers meeting the requirements of AASHTO M 293, satisfy the requirements specified herein and may be used without washers.

6.4.4 *Turn-of-nut tightening.* When turn-of-nut tightening is used, hardened washers are not required, except as specified in Subsection 506.04(f)6.4.3, *Washers*.

At the start of the work, test nut tightening using a device capable of indicating bolt tension a sample of not less than 3 bolt-and-nut assemblies of each diameter, length, and grade to be used in the work. Demonstrate with the test that the method for estimating the snug-tight condition and controlling the turns from snug tight to be used develops a tension not less than 5% greater than the tension required by Table 506-5. Perform periodic re-testing when required.

Following the snug-tightening operation, tighten all bolts in the connection by the applicable amount of rotation specified in Table 506-5. During all tightening operations, do not allow rotation of the fastener part not turned by the wrench. Tighten systematically from the most rigid part of the joint to its free edges.

6.4.5 *Installation of alternative design bolts.* When fasteners that incorporate a design feature intended to indirectly indicate the bolt tension or to automatically provide the tension required by Table 506-5 and conform to Subsection 724.02 are to be

installed, test a representative sample of not less than 3 bolt and nut assemblies of each diameter, length, and grade at the job site with a device capable of indicating bolt tension. Include in the test assembly flat-hardened washers, if required in the actual connection, arranged as in the actual connections to be tensioned. The calibration test must demonstrate that each bolt develops a tension not less than 5% greater than the tension required by Table 506-5. Follow manufacturer's installation procedure. Perform periodic re-testing when required.

When alternative design fasteners that are intended to control or indicate bolt tension of the fasteners are used, install bolts in all holes of the connection and initially tighten sufficiently to bring all plies of the joint into firm contact, but without yielding or fracturing the control or indicator element of the fasteners. Continue to tighten systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners. Proper tensioning of the bolts may require more than a single cycle of systematic partial tightening before final twist-off of the control or indicator element of individual fasteners.

6.4.6 *Direct tension indicator tightening.* When direct tension indicators (DTIs) meeting the requirements of Subsection 724.02 are to be used with high-strength bolts to indicate bolt tension, subject assemblies (bolts, nuts, washers, and DTIs) to verification testing as described in Subsection 506.04(f)6.4.6.1 and install assemblies as specified in Subsection 506.04(f)6.4.6.2.

Unless otherwise approved, install DTIs with the protrusions against the head of the bolt and turn the nut to tighten the fastener. Prevent the element against the DTI from turning during installation and final tensioning. Give special attention to proper installation of flat-hardened washers when direct tension indicator devices are used with bolts installed in oversize or slotted holes.

During verification, do not exceed the maximum allowed number of refusals after snugging.

6.4.6.1 *Verification.* Perform verification testing in a calibrated bolt tension measuring device. Use a special flat insert in place of the normal bolt head holding insert.

Perform three verification tests for each combination of fastener rotational-capacity lot, DTI lot, and DTI position relative to the turned element (bolt head or nut) to be used on the project. Tighten the fastener by turning the element not against the DTI. Prevent the element against the DTI from turning. Conduct verification tests in two stages. Install the bolt, nut and DTI assembly in a manner so that 3 to 5 threads are located between the bearing face of the nut and the bolt head. Tighten the fastener first to the load required in Table 506-7 under verification tension for the grade and diameter of the fastener.

If an impact wrench is used, it shall be deemed acceptable to tighten to a load slightly below the required load and subsequently tighten using a manual

wrench to attain the required tension. Determine and record the number of refusals of a 0.005 inch (0.125mm) tapered feeler gauge in the spaces between the protrusions. The required number of spaces is specified in Table 506-7. Do not exceed the number of refusals listed in Table 506-7 under Maximum Verification Refusals for the grade and diameter of bolt for uncoated DTIs. The maximum number of refusals for coated (galvanized, painted, or epoxy-coated) DTIs shall be no more than the number of spaces on the DTI less one. The DTI lot shall be rejected if the number of refusals exceeds the values in Table 506-7, or, for coated DTIs, if the gauge is refused in all spaces.

Table 506-7
Direct Tension Indicator Requirements

Bolt Size	Verification Tension (kips)		Maximum Verification Refusals		DTI Spaces		Minimum Installation Refusals	
	M 164 A325	M 253 A490	M 164 A325	M 253 A490	M 164 A325	M 253 A490	M 164 A325	M 253 A490
5/8	20	25	1	2	4	5	2	3
3/4	29	37	2	2	5	6	3	3
7/8	41	51	2	2	5	6	3	3
1	54	67	2	3	6	7	3	4
1 1/8	59	84	2	3	6	7	3	4
1 1/4	75	107	3	3	7	8	4	4

Table 506-7
Direct Tension Indicator Requirements (Metric)

Bolt Size	Verification Tension (kips)		Maximum Verification Refusals		DTI Spaces		Minimum Installation Refusals	
	M 164 A325M	M 253 A490M	M 164 A325M	M 253 A490M	M 164 A325M	M 253 A490M	M 164 A325M	M 253 A490M
16	88.96	111.2	1	2	4	5	2	3
20	129.0	164.6	2	2	5	6	3	3
22	182.4	226.9	2	2	5	6	3	3
24	240.2	298.0	2	3	6	7	3	4
27	262.4	373.6	2	3	6	7	3	4
30	333.6	475.9	3	3	7	8	4	4
36	395.9	564.9	3	3	7	8	4	4

After the number of refusals is recorded at the Verification Tension, further tighten the fastener until the 0.005 inch (0.125mm) feeler gauge is refused at all the spaces and a visible gap exists in at least one space. Record the load at this condition and remove the fastener from the tension measuring device. The nut shall be able to be reassembled by hand for the complete thread length of the bolt

excluding thread runout. Reject the DTI lot if the nut cannot be assembled for this length, unless the load recorded is less than 95% of the average load measured in the rotational-capacity test of the fastener lot as specified in the subsection, *Rotational-Capacity Tests*.

If the bolt is too short to be tested in the calibration device, test the DTI as described above on a long bolt in a calibrator to determine the number of refusals at the Verification Tension listed in Table 506-7. Test another DTI from the same lot with a short bolt in a convenient hole in the work. Tighten the fastener assembly until the 0.005 inch (0.125mm) feeler gauge is refused in all spaces and a visible gap exists in at least one space. Then disassemble the fastener, remove it from the hole, and reassemble it by hand for the complete thread length of the bolt excluding thread runout. Reject the DTI lot if the nut cannot be run down this thread length.

6.4.6.2 *Installation.* Perform the installation of fasteners using DTIs in two stages. Prevent the fastener element against the DTI from rotating during each stage of installation. Snug the connection with bolts installed in all the connection holes and sufficiently tighten to bring all the plies of the connection into firm contact. The number of spaces in which a 0.005 inch (0.125mm) feeler gauge is refused in the DTI after snugging shall not exceed those listed under Maximum Verification Refusals in Table 506-7. If the number exceeds the values in the table, remove the complete assembly (bolt, nuts, washers, and DTI) and install another complete assembly followed by resnugging.

Further tighten the connection until the number of refusals of the 0.005 inch (0.125mm) feeler gauge shall be equal to or greater than the number listed under Minimum Installation Refusals in Table 506-7. Tighten all fasteners systematically from the most rigid part of the connection to the free edges in a manner that will minimize relaxation of previously tightened fasteners If the fastener is tightened so that no visible gap in any space remains, remove and replace the complete assembly.

6.4.7 *Inspection.* Inspect, in the presence of the Engineer, the tightened bolts using an inspection torque wrench, unless alternative fasteners or DTIs are used, allowing verification by other means. Inspect within 24 hours of bolt tightening to prevent possible loss of lubrication or corrosion on tightening torque.

Individually place three bolts of the same grade, size, and condition as those under inspection in a device calibrated to measure bolt tension. Perform this calibration operation at least once each inspection day.

Use a washer under the part turned in tightening each bolt if washers are used on the structure. If washers are not used on the structure, use the same specification material which abuts the part turned in the tension measuring device as used on the structure. In the calibrated device, tighten each bolt by any convenient means to the specified tension. Apply the inspecting wrench to the tightened bolt to determine the torque required to turn the nut or head 5°,

approximately 1 inch (25mm) at a 12-inch (300mm) radius, in the tightening direction. Use the average of the torque required for all three bolts as the job-inspection torque.

Select at random in each connection 10% (at least two) of the tightened bolts on the structure represented by the test bolts, and apply the job-inspection torque to each selected bolt with the inspecting wrench turned in the tightening direction. If this torque turns no bolt head or nut, the bolts in the connection will be considered to be properly tightened. If the torque turns one or more bolt heads or nuts, apply the job-inspection torque to all bolts in the connection. Tighten and reinspect any bolt whose head or nut turns at this stage. As an option retighten all bolts in the connection and re-submit for inspection.

7. *Welding.* Welding, welder qualifications, prequalification of weld details, and inspection of welds shall conform to ANSI/AASHTO/AWS Bridge Welding Code D1.5.

Do not weld or tack brackets, clips, shipping devices, or other material not required to any member unless shown on the approved drawings.

(g) **Erection.**

1. *General.* Provide all tools, machinery, and equipment necessary to erect the structure. Falsework and forms shall conform to Section 502.
2. *Handling and storing material.* Place material stored at the job site on skids above the ground. Keep material clean and properly drained. Place and shore girders and beams upright. Support long members, such as columns and chords, on skids placed near enough together to prevent damage due to deflection.

   If the contract documents are for erection only, check the material received against shipping lists and report promptly in writing any shortage or injury discovered. After material is received, the Contractor is responsible for any damage to or loss of material.
3. *Bearings and anchorages.* Furnish and install bridge bearings and anchors according to Section 509. If the steel superstructure is to be placed on a substructure that was built under a separate contract, verify that the concrete pedestals have been correctly constructed before ordering material.

   If actual centerline bearing of the assembly does not line up horizontally within ±2 inches (50mm) of the vertical bearing stiffener plates, weld additional vertical bearing stiffeners to the beam or girder.
4. *Erection procedures.*

   4.1 *Conformance to drawings.* Erect according to approved erection drawings and contract documents. Modifications to or deviations from the approved erection procedure will require revised drawings and verification of stresses and geometry.

   4.2 *Erection stresses.* Allow for erection stresses induced in the structure as a result of the use of a method of erection or equipment that differs from that previously approved, and that will remain in the finished structure as locked-in stresses. Provide additional material, as needed, to keep both temporary and final stresses within the allowable limits used in the design.

Provide temporary bracing or stiffening devices to accommodate handling stresses in individual members or segments of the structure during erection.

4.3 *Maintaining alignment and camber.* During erection, support segments of the structure in a manner that will produce the proper alignment and camber in the completed structure. Install cross frames and diagonal bracing as necessary during erection to provide stability and assure correct geometry. As necessary, provide temporary bracing at any stage of erection.

5. *Field assembly.* Accurately assemble as shown on the erection drawings and required by match-marks. Carefully handle the material. Do not hammer, damage, or distort the members. Clean bearing surfaces and permanent contact surfaces before assembly.

Assemble splices and field connections with at least two cylindrical erection pins per part (four minimum per splice or connection). A plate girder splice requires for example, at least four cylindrical erection pins for the top flange splice, four pins for the web splice, and four pins for the bottom flange splice. These provide two pins for each part. Place the pins in the corner holes of the splice plates. Where field bolted diaphragms are shown, erect at least every other diaphragm at the time the beams are set in place with bolts or driftpins placed in 50% of the connection holes. Where field welded diaphragms are shown, erect all diaphragms as the beams are set in place by one $^{3}/_{4}$ inch (20mm) make up bolt at each connection point.

Install more cylindrical erection pins, if necessary, to accurately align the parts. Fill the remaining holes in the connection with bolts and tighten systematically from the most rigid part of the connection to the free edges. Remove cylindrical erection pins and replace with tightened bolts.

Release temporary erection supports at a splice or connection only after all bolts are installed and tightened. Show special assembly and support situations on the erection and falsework drawings.

Fitting-up bolts may be the same high-strength bolts used in the installation. If other fitting-up bolts are required, use the same nominal diameter as the high-strength bolts. Use cylindrical erection pins $^{1}/_{32}$ inch (0.75mm) larger than the bolts.

6. *Pin connections.* Use pilot and driving nuts in driving pins. Furnish these items without charge. Drive the pins so that the members will fully bear on the pins. Screw pin nuts tight and burr the threads at the face of the nut with a pointed tool.

7. *Misfits.* Correction of minor misfits involving minor amounts of reaming, cutting, and chipping may be done, if approved. Any error in the shop fabrication or deformation resulting from handling and transporting will be cause for rejection.

The Contractor shall be responsible for all misfits, errors, and damage and shall make the necessary corrections and replacements.

(h) **Expansion Joints.** Fabricate expansion joints in accordance with the requirements of this section. Install expansion joints in accordance with the requirements of Section 504.

Submit complete working drawings for fabrication and installation of expansion joints. Include the joint manufacturer's instructions for proper installation of the joint on the drawings.

Show the joint opening dimension for an ambient temperature of 60°F (15°C) and adjustments to that dimension due to temperature variations.

Accurately fabricate expansion joints to conform to the specified concrete floor section, matching cross slopes and break points. Assemble expansion joints in the shop and check for fit, then match mark for shipment.

For sealed expansion joints, fabricate the steel receptors to be continuous the full length of joint including 6 inch (150mm) extensions. Minimize the number of splices in the steel receptor. To splice, use a partial penetration weld, ground smooth. Do not weld in the areas in contact with the neoprene.

Provide and install a neoprene gland continuous the full length of joint including 6 inch (150mm) extensions. At locations where joints are shown to be mitered for skew of 35° and greater, splice the neoprene by vulcanizing or other approved method that provides strength and durability equal to unspliced neoprene. Make splices permanently watertight.

506.05. METHOD OF MEASUREMENT.

Pay quantities for each type of *structural steel* and iron will be measured by the pound (kilogram), computed from the dimensions shown on the approved shop drawings using the following rules.

Weight shall be computed on the basis of the net finished dimensions of the parts as specified in the contract documents and using the unit weights given in Table 506-8. Approved substituted sections that are larger than those specified, shall be measured by the weight of the originally specified sections. Deductions shall not be made for cuts, clips, copes, bolt holes, pin holes, or weld joint preparation. Waste necessitated by girder camber or curve shall not be measured. Changes in quantities resulting from alternative details proposed by the Contractor and approved as part of the drawings shall not be considered changes ordered by the Engineer.

Table 506-8
Unit Weights of Steel and Iron Density, lb/ft^3 (kg/m^3)

Steel, Rolled or Cast	490 (7850)
Cast Iron	445 (7130)
Malleable Iron	470 (7530)
Wrought Iron	487 (7800)

The weight of rolled shapes shall be computed on the basis of their nominal weight per foot as specified in the contract documents. If weight is not specified in the contract documents, use AASHTO M160, or an approved handbook.

The weight of plates shall be computed on the basis of the nominal weight for their width and thickness as specified in the contract documents with no allowance for overruns.

The weight of castings shall be computed from the dimensions shown on the approved shop drawings, deducting for open holes. To this weight shall be added 5 percent allowance for fillets and overrun. The weight shall include, steel and iron castings, steel or cast iron pipe for drains and all minor items necessary to complete the work satisfactorily according to the Plans. If approved, scale

weight may be substituted for computed weight in the case of castings or small complex parts for which accurate computations of weight would be difficult.

The weight of heads, nuts, single washers, DTIs, and threaded stick-through of all high tensile strength bolts, both shop and field, shall be included as specified in Table 506-9.

Table 506-9
Weight Per 100 Bolts

Bolt Size, inches	Weight per 100 bolts pounds
5/8	31.7
3/4	52.4
7/8	80.4
1	116.7
1 1/8	165.1
1 1/4	212.0

Table 506-9
Mass Per 100 Bolts (Metric)

Bolt Size, mm	Weight per 100 bolts kg
16	14.4
20	23.8
22	36.5
24	53.0
27	75.0
30	96.4
36	127.3

The weight of anchor bolt assemblies (threaded bars, nuts, and washers), anchor plates not embedded in concrete, and diaphragm bolt assemblies (threaded-end bars, couplers, nuts, plates, and washers) for diaphragms between prestressed concrete girders shall be measured as structural steel. The weight of threaded bars shall be computed on the basis of smooth bar of the specified diameter. The weight of nuts and washers shall be determined from approved handbooks.

The weight of weld metal, temporary erection bolts, drift pins, driving caps, shop and field paint, galvanized coating, boxes, crates, and other containers used for shipping, and materials used for supporting members during transportation and erection, will not be included.

The weight of any additional material required under Subsection 506.04(g)4.2 to accommodate erection stresses resulting from the Contractor's choice of erection methods will not be included. The weight of additional bearing stiffeners required under Subsection 506.04(g)3 will not be included.

Metal expansion joints shall be measured as specified in Section 504.

506.06. BASIS OF PAYMENT.

The accepted quantities, measured as provided above, will be paid at the contract price per unit of measurement for the pay item listed below that is shown in the bid schedule. Payment will be full compensation for the work prescribed in this section.

(A) STRUCTURAL STEEL ..... POUND (KILOGRAMS)

SECTION 507
TIMBER STRUCTURES

507.01. DESCRIPTION.

This work shall consist of constructing timber structures and the timber portions of composite structures, in accordance with these specifications and in reasonably close conformity with the details specified in the contract documents or established by the Engineer.

It shall include furnishing, preparing, fabricating, erecting, treating, and painting of timber. All timber, treated or untreated, shall be of the specified species, grades and dimensions. Also included shall be any required yard lumber of the sizes and grades specified and all hardware required for timber connections and ties.

507.02. MATERIALS.

(a) Lumber and Timber (Solid Sawn or Glued Laminated). Use sawn lumber and timber conforming to the Specifications for Wood Products, AASHTO M168.

Structural glued laminated timber shall conform to the American National Standard ANSI/ AITC A-190.1, Specification for Structural Glued Laminated Timber. The separate laminations shall not exceed 2 inches in net thickness. They may be comprised of pieces end-joined to form any length, of pieces placed or glued edge to edge to make wider ones, or of pieces bent to curved form during gluing. On glued-laminated structural members that are not to be preservative treated, apply an approved end sealer after end trimming of each completed member.

The grades of timber used for various structural purposes shall be as specified in the contract documents.

Furnish the following certificates of compliance to the Engineer, as appropriate, upon delivery of the materials to the job site:

- For timber and lumber, a Type B certification by an agency certified by the American Lumber Standards Committee that the timber or lumber conforms to the grade, species and any other specified requirements.
- For glued-laminated timber, a Type B certification by a qualified inspection and testing agency that the glued-laminated timber complies with the grade, species and other requirements outlined in ANSI/AITC A 190. 1.
- If the wood is to be treated with a preservative, furnish a Type B certification for the preservation treatment.